ORIGINAL RESEARCH

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Force and Accuracy Throws by Older Adult Performers

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Older adults threw tennis balls for force and accuracy to examine their adaptability to different task demands. Twenty-one (13 women, 8 men) participants were videotaped as they performed five force and five accuracy throws. The developmental level of each throw was determined; resultant ball velocities also were examined. Roberton's (1977, 1978) movement components were used in the former analysis. The typical pattern of gender differences occurred for both movement component and velocity measures. Men performed at higher levels than women. Only minor force versus accuracy differences were found in the movement patterns used by either men or women; none of these differences were significant. Clear task differences occurred for ball velocities. Men's forceful throws were faster than those for accuracy; women's throws did not differ for the two tasks. The generally lower developmental level of women's throws accounted for gender differences in velocity. Insufficient task differences may explain the lack of clear contrast in movement patterns.

Key Words: developmental sequences, motor development, aging

Much of the research on motor performances of older adults has focused on typical activities of daily living such as locomotion, driving, and dressing oneself. The speed used for testing many of these tasks is self-selected. In much of this research, age related declines are reported for most tasks involving comparisons between older and younger adults. Findings of research based only on this single, self-chosen speed are criticized for at least two related reasons. First, they gave little or no insight into how or even if older adults perform movements requiring other levels of exertion. Second, Craik (1989) suggested the pattern of decline often seen for many tasks was speed related rather than age related. That is, Craik (1989) suggested that older subjects typically *choose* to move more slowly than younger subjects. Their selection of a slower movement speed results in many differences often assumed to be age related. When movement speed is equal for younger and older adults, investigations of locomotor activities (Craik, 1989; Williams, 1992) result in few age related differences.

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The overarm throw is a skill that often requires varying levels of effort, depending on task constraints. Although it is not a motor skill typically performed by older adults, it is a complex movement skill requiring multisegmental coordination. In a forceful throw, segments move through extensive ranges of motion that require precise timing of many body segments. Maximum force is generated when segmental velocities reach their peaks sequentially (Kreighbaum & Barthels, 1990). In contrast, a throw for accuracy (assuming a relatively short distance) results in the use of fewer segments and these are moved through smaller ranges of motion with greater simultaneity (Kreighbaum & Barthels, 1990). Only enough force to reach the target is necessary. Timing between body segments remains important for a proper release so that the ball reaches the target. Of course, requirements of many throws combine specific levels of force and accuracy and fall between these two extremes. For example, an accuracy throw made to a target placed a moderate distance away requires the performer to use some force while maintaining accuracy.

In the examples given above, task requirements constrained the type of throw performers might use to be successful. Newell (1986) described task requirements as but one factor that might influence the specific motor pattern used in a given situation. Environmental constraints are general factors (weather, gravity, barometric pressure) external to the individual. Organismic factors are specific to individuals (e.g., strength, body size, developmental status). Newell suggested these three types of factors interact to determine the specific characteristics of a motor pattern at any given time. Dynamical systems proponents (e.g., Thelen & Ulrich, 1991) call these constraints control parameters. They view them as factors that, when changed beyond some critical value, can move the actor from one performance state to another. Systematic investigation of control parameters is only beginning (Jensen & Phillips, 1991; Newell, Scully, Tenenbaum, & Hardiman, 1989).

In the overarm throw, changing a control parameter like required force could result in a shift from one movement pattern to another. Roberton (1977, 1978) and others (Haywood, Williams, & VanSant, 1991; Roberton & Halverson, 1984) described qualitative changes, called developmental sequences, for movement components (e.g., trunk, forearm, humerus) in the overarm throw for force (Figure 1). These sequences described the orderly changes occurring in the throw from least to most advanced.

In the language of dynamical systems, changing control parameters could force a shift to higher levels of the developmental sequence. Conversely, a change in control parameters could result in regression to a less advanced pattern. Smaller changes in task requirements might result in smaller, possibly quantitative, changes within a particular developmental level. For example, qualitative shifts in trunk action consist of no action, or forward/backward movement, to unitized rotation of the body (block rotation), to pelvic-led differentiated rotation of the hips and shoulders. While critical changes in force requirements might lead to a shift from block to differentiated rotation, smaller changes in force might simply result in more trunk rotation (say from 20 to 60°) still described by the block category.

Roberton (1987) and Langendorfer (1990) investigated the influence of task requirements on throwing patterns. They hypothesized that changing task constraints would result in changes in throwing patterns. In her study of 3- to

Trunk Action Component

Level 1. No trunk action or forward backward action
Level 2. Upper trunk rotation or trunk "block" rotation
Level 3. Differentiated rotation

Humerus Action Component

Level 1. Humerus oblique
Level 2. Humerus aligned but independent
Level 3. Humerus lags

Forearm Action Component

Level 1. No forearm lag
Level 2. Forearm lag
Level 3. Delayed lag

Foot Action Component

Level 1. No foot action
Level 2. Ipsilateral foot action
Level 3. Contralateral foot action, short step
Level 4. Contralateral foot action, long step

Preparatory Backswing Action

Level 1. No backswing
Level 2. Elbow and humeral flexion
Level 2.5. Humeral lateral rotation
Level 3. Circular, upward backswing
Level 3.5. Shortcut circular, downward backswing
Level 4. Circular, downward backswing

Figure 1. Developmental sequences for movement components of the overarm throw for force. Trunk, humerus, forearm, and foot actions are modified from Roberton and Halverson (1984). Backswing action is modified from Haywood et al. (1991).

8-year-olds, Roberton (1987) hypothesized a shift to less advanced movement patterns as subjects went from nontarget to target conditions. On the contrary, most subjects did not change the pattern they used, despite task requirements. However, some subjects appeared to become more variable in their actions. Roberton (1987) suggested that developmental status (an organismic constraint) might have interacted with task constraints. Most subjects in her investigation were categorized at immature developmental levels, from which little if any additional qualitative regression was possible.

Langendorfer (1990) examined the influence of changing task constraints from force to accuracy on fourth-grade and adult subjects. For male subjects, regardless of age, he found a significant change to less advanced movement patterns as task requirements shifted from force to accuracy. Females showed change in a similar direction with task changes, but most were too small to result in statistical significance.

This investigation used the same manipulations as Langendorfer (1990) to determine whether older subjects shifted from one state to another as task requirements moved from force to accuracy. This study is part of a larger, ongoing longitudinal study of a group of active, older adults (Haywood et al., 1991; Williams, Haywood, & VanSant, 1990, 1991). It represents the 4th year of data collection for many of these subjects. The first 3 years of data collection emphasized throws for force. Accuracy throws were added in the 4th year. The Year 4 data will be the focus of this investigation.

Methods

SUBJECTS

Participants in this study were 21 active older adults between 66 and 82 years of age from the St. Louis area. There were 13 women (mean age 75.1 yrs, *SD* 4.5 yrs) and 8 men (mean age 74.9 yrs, *SD* 3.5 yrs). Subjects were volunteers who participated in the Active Adult Program at the University of Missouri–St. Louis. All read and signed informed consent forms before testing.

MOVEMENT TASK AND INSTRUMENTATION

A sagittal view of the subjects was videotaped from about 9.15 m using a Panasonic video camcorder (Model PV 330D). The camcorder was equipped with a high speed 1/1000-s shutter and recorded movement at approximately 30 fields per second. Videotaping took place indoors in a large gymnasium. The subjects performed five throws for maximum force as part of the longitudinal study on forceful throwing. They also completed an additional five throws for accuracy. Forceful-throwing trials always preceded accuracy trials since the forceful throws were part of the longitudinal study.

When making forceful throws, subjects were instructed to throw tennis balls as hard as they could toward an unmarked wall approximately 36.6 m away. For accuracy throws, tennis balls were thrown at a 2.44-m square target placed 10 m away. The target consisted of two vertical poles placed 2.44 m apart and a horizontal crosspiece placed at the 2.44-m height. Subjects were instructed to throw through this target area. Target size was small enough to add an accuracy constraint to the throwing task, but large enough to enable most subjects to meet the accuracy criterion.

DATA REDUCTION AND ANALYSIS

A total of 208 trials were available for analysis, 104 each of the force and accuracy throws. Two trials were lost from two subjects when the field of view was obscured. Preliminary data reduction took two forms. The first phase involved classifying all the trials according to their developmental level. The categories used had been hypothesized and validated (Figure 1) by Roberton (Roberton & Halverson, 1984) and by Haywood and colleagues (1991). The first two authors (K.W. and K.H.) viewed the trials using videodecks that enabled them to slow the speed of the action as well as to view movements field by field. Before classifying all the trials, intra- and interrater objectivity criteria of 85% exact agreement were met. Twenty trials were selected randomly from across all subjects for this test. Intrarater agreement was 100% for the trunk action, 96% for the foot, and 92% for forearm, humerus, and backswing actions. Interrater agreement was 100% for the trunk and foot actions, 96% for the humerus, and 88% for the backswing and forearm actions.

The remaining data (188 trials) were then classified. Modal values were determined for each movement component for each subject. Modes were analyzed for throw-type comparisons for the men's and women's data using Friedman two-way analyses of variance. Gender differences for all movement components were tested in 2 × 2 (Gender × Throw-type) multivariate mixed model analysis of variance (Schutz & Gessaroli, 1987).

In the second part of data analysis, the final three trials of each type of throw were digitized for each subject. Previous research (Langendorfer, 1987; Roberton, 1978) showed that subjects used the same movement pattern consistently on nearly 90% of their trials. In our data, four of the five trials were placed at the same developmental level 91.5% of the time. These findings, coupled with the relationship between velocity and movement categories (Roberton & Konczak, 1990), suggested to us that three trials were enough to determine subjects' velocity performances. A video/computer motion analysis system (Peak Performance Technologies, Inc., Englewood, CO) was used to obtain horizontal and vertical coordinates for the ball's position before and after release. A measure of resultant ball velocity at release was used in additional analyses. All three throws for the two conditions were analyzed using a 2 × 2 × 3 (Gender × Throw-type × Trials) repeated measures analysis of variance (ANOVA) to examine gender and throw-type differences. Alpha was set at .01.

Results

MOVEMENT COMPONENTS

No statistically significant differences ($p<.05$) occurred for throw-type comparisons in any component for either men or women (Table 1). Inspection of the modes (Table 1) suggests there were small shifts toward lower developmental levels for accuracy throws, especially for the men. For men, the change toward a lower developmental level was seen for the backswing, forearm, foot, and humerus actions. No quantitative change in categorizations occurred for the trunk action. For women, change toward a lower developmental level was observed for backswing and humerus actions. The women demonstrated a shift toward a *higher* level foot action. No quantitative change in categorizations occurred for forearm or trunk actions.

Because both male and female samples were small, idiographic inspection of the modal data was conducted for changes that may otherwise be masked when data are averaged across subjects. Throw-type changes occurred for some men and women for most movement components. Both progression and regression were noted for the women. For the humerus, three subjects were classified at Level 2 for forceful throws and Level 1 for accuracy throws. Two additional subjects actually exhibited more advanced behaviors. They changed from Level 1 to Level 2 as task requirements shifted from force to accuracy. Similar progressive and regressive changes were noted for the trunk and foot actions. One woman

Table 1 Average Modal Values of Developmental Levels in Overarm Throwing by Gender and Force/Accuracy Conditions

Movement component	Force		Accuracy	
	M	*SD*	*M*	*SD*
Females				
Backswing (6)[a]	3.04	0.5[b]	2.92	0.5
Forearm (3)	1.15	0.4	1.15	0.4
Foot (4)	2.85	0.7	3.08	0.4
Humerus (3)	1.38	0.5	1.31	0.5
Trunk (3)	1.92	0.3	1.92	0.3
Males				
Backswing (6)	3.69	0.4	3.56	0.6
Forearm (3)	1.88	0.4	1.63	0.5
Foot (4)	3.38	0.5	3.13	0.4
Humerus (3)	1.88	0.4	1.75	0.5
Trunk (3)	2.00	0.0	2.00	0.0

[a]Number of steps within the developmental sequence (see Figure 1). [b]All force/accuracy differences are nonsignificant, $p > .05$.

advanced and one regressed in trunk action; one advanced and two regressed in foot action. No changes were seen for the forearm action. Three women were classified at a lower developmental level for the backswing when they threw for accuracy.

Only regressions were observed for the men as task requirements changed from force to accuracy. For humerus and backswing actions, one man demonstrated a less advanced motor pattern. Three men used a less advanced forearm pattern, and two changed their foot action. No changes occurred in trunk actions.

Gender differences also were examined across the throw types. The overall multivariate analysis was significant: $F(5, 15) = 850.98$, $p<.001$. Significant gender differences occurred for backswing ($p<.01$), forearm ($p<.01$), and humerus components ($p<.05$). Women were categorized at lower developmental levels than men for each of these movement components (Table 2). No significant gender differences occurred for foot ($p=.10$) or trunk ($p=.27$) actions.

VELOCITY MEASURES

The resultant velocity data were analyzed in a 2 × 2 × 3 (Gender × Throw-type × Trials) repeated measures ANOVA (Figure 2). The Gender × Throw-type interaction reached significance, $F(1, 19) = 10.8$, $p=.004$. There were significant main effects for gender, $F(1, 19) = 47.5$, $p<.01$; and throw-type, $F(1, 19) = 9.8$, $p=.006$. A marginally significant trials effect occurred, $p=.03$. Examination of the data suggested no across-trials trend for individuals. An intraclass correlation coefficient was computed to confirm this finding. Intraclass R was .85, suggesting trial-to-trial consistency for subjects. As shown in Figure 2, males performed

Table 2 Average Modal Values for Developmental Levels of Throwing by Gender

	Females		Males		
Component	*M*	*SD*	*M*	*SD*	*p* value
Backswing (6)[a]	2.98	0.5	3.63	0.5	<.01
Forearm (3)	1.15	0.4	1.75	0.5	<.01
Foot (4)	2.92	0.6	3.25	0.5	n.s.
Humerus (3)	1.35	0.5	1.81	0.4	<.05
Trunk (3)	1.92	0.3	2.00	0.0	n.s.

[a]Number of steps within the developmental sequence (see Figure 1).

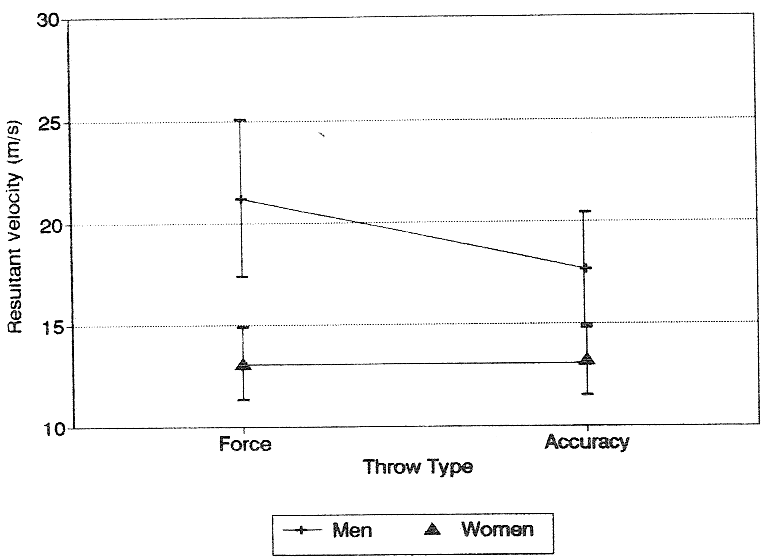

Figure 2. Average resultant ball velocities by gender and throw type (force vs. accuracy).

throws for force using faster ball velocities than accuracy throws. Females used the same ball velocity for both types of throws. Males also threw the ball faster than females, regardless of type of throw.

Discussion

The pattern of gender differences often reported for throwing tasks was reaffirmed by this investigation. Males threw using faster ball velocities and more advanced movement patterns than females. This pattern is seen in children as young as 3 years of age (Thomas & French, 1985) and as old as adults in their 70s (Williams et al., 1990, 1991). Of greater interest, however, was the interaction between gender and throw type. Men demonstrated clear change in the velocity generated to perform the two tasks; change was less clear in the motor patterns used. In contrast, women threw using the same velocity for the two conditions. They made few movement pattern changes for the two types of tasks.

There were clear differences in the velocities that male subjects generated for the two throw types. The men used a faster ball velocity for forceful throws (21.2 m/s) than for their accuracy throws (17.6 m/s). In contrast, women used the same velocity, around 13.0 m/s, regardless of type of throw. The pattern of force versus accuracy differences found for men's ball velocities often is assumed to occur when task requirements shift from force to accuracy. This change results from the tradeoff between producing speed and producing accuracy (Schmidt, 1988). Because no velocity differences occurred for the women, the force/accuracy manipulation apparently did not have the same impact for them as it had for men in this investigation. In fact the 10-m distance may have added an inadvertent force constraint to the task for many women. So, rather than reducing or minimizing force requirements in the accuracy task, many women may have needed to throw forcefully to reach the target.

Regardless of gender, small and nonsignificant force/accuracy differences resulted when movement pattern was considered. Both men and women tended to use less advanced patterns for accuracy throws. Men showed this tendency toward a lower developmental level for four movement components. Women exhibited it only for backswing and humerus actions. These women may exhibit only small amounts of change in their movement patterns because they were largely at low developmental levels even for forceful throws. They could not regress any further. Additional regression when accuracy throws were performed was difficult, especially for forearm and humerus actions (see Table 1).

Men were classified at higher developmental levels than women for most movement components. Individuals using more advanced movement patterns appear to have more movement options from which to select for different task conditions (Roberton, 1987). The tendency for men to use less advanced movements when throwing for accuracy suggests the men exercised their ability to use these options.

Alternatively, it may be that only small changes occurred for women because of the tasks themselves. For forceful throws, subjects stood approximately 35 meters from a wall and threw as hard as possible toward it. No suggestion was made that subjects should try to reach the wall, however. For accuracy throws, a target was placed 10 m away and subjects were told to throw through the target. The intent of this manipulation was to add an aiming component for subjects' accuracy throws as well as to decrease the force required. For some women, however, accuracy throws may have resulted in the same or an increased force requirement. When no target was present, subjects performed at some level they perceived as maximally forceful. The wall was far enough away that it was not viewed as a possible goal; that is, many subjects knew they could not hit it. Balls thrown with this constraint may or may not have traveled 10 m. When the target was added, however, subjects could view this as a distance goal.

This change could require some subjects to throw harder than in the forceful condition. Idiographic data suggest this might be the case for some female subjects. Four subjects used more advanced movement patterns in the accuracy condition than they had for the force task. One subject advanced in two movement components; three others advanced in one component. Observation of subjects as they threw suggested that most of them reached the target most of the time. Although the distance they threw in the forceful task was not measured, it was noted that some women barely reached the 10-m distance, implying less velocity.

Five women did show regression for at least one movement component in the accuracy condition. The four others remained the same for the two conditions. These findings suggest the force/accuracy manipulation was appropriate for many subjects but may have maintained or increased the force requirement for others. Further study of accuracy throws made from different distances clearly is necessary.

Because velocity differences were found only for the men, changes in developmental status might be related largely to their lowered throwing velocity under the accuracy condition. Roberton and Konczak (1990) showed the relationship between velocity and developmental level. Logically, the men lowered their throwing velocity in order to hit the target. In turn, this lower velocity required involvement of fewer body segments (Kreighbaum & Barthels, 1990). Less advanced developmental levels are characterized by the use of fewer segments moved through smaller ranges of motion.

Because trends toward change in movement pattern occurred most strongly for men, despite clear velocity changes, the validity of the movement categories themselves might be questioned. Alternatively, the relationship between ball velocity and developmental level described by Roberton and Konzcak (1990) might be questioned. Further examination of the data from this investigation makes either conclusion premature. Instead the categories seem broad enough to encompass changes that might actually contribute to the size of velocity changes seen, without compromising the integrity of the categories themselves. That is, most categories describe qualitative change from one developmental level to another. Within many categories, however, quantitative changes also may occur. For example, within the trunk action, block rotation refers to rotation of the trunk ranging from a few degrees to 100° or more. Humeral actions would be classified as aligned but independent whether the humerus was swung a few degrees forward or 90° forward. In these two examples, the outcome (velocity) of throws made from the two extremes could be quite different. Still, subjects would have been classified identically.

In this investigation, categorization of trunk actions provides a clear example of this phenomenon. Virtually all subjects were placed at Level 2, block rotation. Only two women were placed at Level 1, no rotation, or extension/flexion (one each for the force and accuracy conditions). For virtually *all* throws, however, men used greater rotation than women. Although rotation was not measured, since only sagittal views of subjects were available, men appeared to use greater rotation when performing forceful as opposed to accuracy throws.

Closer examination would likely result in similar findings for other movement components. This example suggests that the men in this study were more adaptable to changing task conditions than the women, even when the way they were classified did not change. Of course these differences are likely due to gender related differences in developmental level rather than to specific gender differences per se. These results suggest that *both* types of information, movement pattern and outcome, are necessary for a thorough and accurate evaluation of motor skill performances such as throwing.

In summary, ball velocity changes related to task requirements were clear for older men but not for older women participating in this investigation. Only small changes in movement patterns occurred for some components when subjects shifted from a forceful to an accuracy throw. Accuracy requirements for advanced throwers, primarily men, were not sufficient to require a change in the motor pattern they used. Less advanced throwers, primarily women, had to focus mainly on force requirements to project the ball as close to the target as possible. Because these changes occurred primarily along gender lines for the older adults, further investigation is needed with more skillful, older women and with more sensitive accuracy tasks. These data would give a clearer picture of the extent to which older adults can vary their movement patterns as they relate to task or environmental changes.

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